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DESIGN FOR BUILDABILITY AND THE DECONSTRUCTION CONSEQUENCES

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SUMMARY

The disassembly of a building may sound like the opposite of its assembly, but in practice it seldom occurs this way. The slow careful process of construction requires large numbers of people, large quantities of materials, and long periods of time. The reversal of this sequence is usually practiced as demolition and requires very little of the time and effort of the construction sequence. Despite these usual differences, if controlled and sequential disassembly were practiced instead of demolition, the construction and disassembly sequences could essentially be the same, one simply being the reversal of the other.

This paper presents a discussion of buildability and the notion that designing a building for ease of assembly might also lead to ease of disassembly for future reuse and recycling. Principles of design for ease of assembly, or ease of construction, can be adapted to become principles of design for disassembly.

If such reverse sequencing were to be attempted and designed for, both heuristic principles of buildability and broader philosophies or approaches to better assembly, should be valuable sources of knowledge in designing for disassembly.

KEYWORDS: buildability, construction, deconstruction, design, disassembly.

INTRODUCTION

The way in which we currently design and construct buildings in the industrialised world, is wasteful and irresponsible. Most buildings are designed with a life expectancy of just a few decades with no consideration of what will happen after their service life. In fact up to one third of all solid waste going to landfill comes from building construction and demolition [1]. The negative environmental impacts of this waste are substantial.

Such waste can be avoided or reduced by increasing the current rates of reuse and recycling of building materials and components. One of the main obstacles to such reuse is that buildings are not designed for such ease of disassembly, and a developed knowledge base for design for disassembly does not yet exist.

There are however a number of related fields of knowledge that might offer information that will be of use in designing for disassembly. These areas include: industrial design, architectural technology, structural engineering, building maintenance, and buildability. Research into this last area of buildability has already established some broad concepts and philosophies of how to achieve ease of assembly, as well as heuristic design principles of design for assembly. Information on how to design for ease of assembly should be transferable to create knowledge of how to design for disassembly.

DEFINING BUILDABILITY

Several researchers and organisations have offered definitions of buildability, but the widely accepted definition [2] is that of the Construction Industry Research and Information Association (CIRIA), which quite explicitly states that 'buildability is the extent to which the design of a building facilitates ease of construction, subject to the overall requirements for the completed building' [3].

Further definitions of buildability share the two main points of this definition; that it is about designing for ease of construction, and that it is within a holistic vision of the building project. The CII (Construction Industry Institute) at the University of Texas refers to buildability as the 'optimum integration of construction knowledge and experience…. to achieve overall project objectives'. The CII at the University of South Australia defines buildability as 'a system for achieving optimum integration of construction knowledge in the building process…. to achieve maximisation of project goals'. Other definitions refer to ' building efficiently…. to agreed quality levels' and the extent to which decisions 'facilitate the ease of construction and the quality of the completed project'. [4]

These definitions share an important implication, which CIRIA discusses. Any principles or philosophies of buildability must sit within a set of ‘overall requirements for the completed building’, which may in some cases be in conflict with the principles of buildability. This is to say that the overall project goals may actually restrict the buildability of the project, such that heuristic principles of buildability may not necessarily be appropriate in all cases.

Such a conflict is also evident in previously developed principles of design for disassembly [5] and the overall requirements for the completed building. This way in which the principles of buildability must be qualified reinforces the similarities that such principles might have with principles of design for disassembly. This similarity of application supports the potential for borrowing these principles of buildability for use in developing a knowledge base for design for disassembly.

RESEARCH INTO BUILDABILITY

Research into buildability can be split into two types: that which looks at broad systems of construction and the building process in general, and that which looks at particular heuristic principles of how to design buildings for better assembly or constuctability.

Buildability Systems

Much of the more recent research into buildability has focused on the broader view of what it takes to make a building easier to construct. In particular, research at the University of Newcastle, Australia [6][7], has developed a conceptual model of buildability. This model can be used to identify buildability factors within project specific environments. Development of the model relies on a systems view of the design-construction process. This model seeks to understand the entire construction process as a system of interrelated activities and people, each of which may have an impact on the construction process (refer to Figure 1).

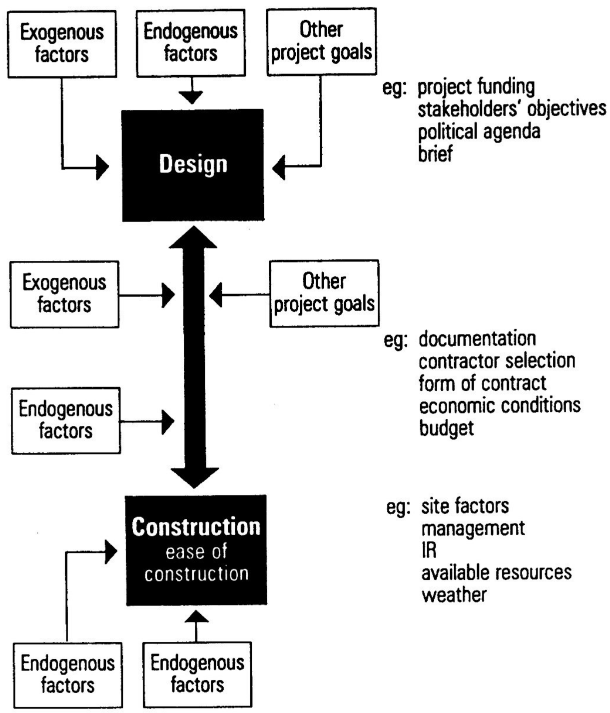

Figure 1 A systems view of the design-construction process [8].

Using such a systems approach the researchers have identified three dimensions to the model of buildability. These are: the participants, the buildability factors, and the stages of the building life cycle. The participants might include: clients, users, financiers, regulatory bodies, contractors, designers, and numerous others. Buildability factors are the cultural and technological activities that might be undertaken to achieve ease of assembly. The stages of the building life cycle will include: feasibility study, design, documentation, construction, commissioning, and demolition or deconstruction. A graphic representation can be made of this model of three dimensions (refer to Figure 2).

This model allows 'the identification and characterisation of the most influential factors impacting on project buildability, to enable the negative effects of these factors to be mitigated, and the positive effects enhanced, in terms of the overall project objectives' [9]. The importance of this model, with respect to informing design for disassembly knowledge, is in identifying the complexity of the system that allows or disallows good buildability. Since demolition, deconstruction, or disassembly is at the end of the project life cycle in this model, a similarly complex system must be understood to effectively design for disassembly. This is to say that while a set of design principles can be developed for design for disassembly, they must be understood within a broader context of the overall project and its systems environment.

This type of modelling of the construction process and context to understand buildability has also been investigated by other researchers who have used a systems approach [10]. The assembly process can be seen as a system in which the building gains mass through the conversion of materials into components, components into sub-assemblies, and sub-assemblies into buildings. Buildability then allows for ease of progress from materials to building. Design for disassembly then should consider the ease of the reversal of this process, loosing mass, from building through sub-assemblies and components to materials.

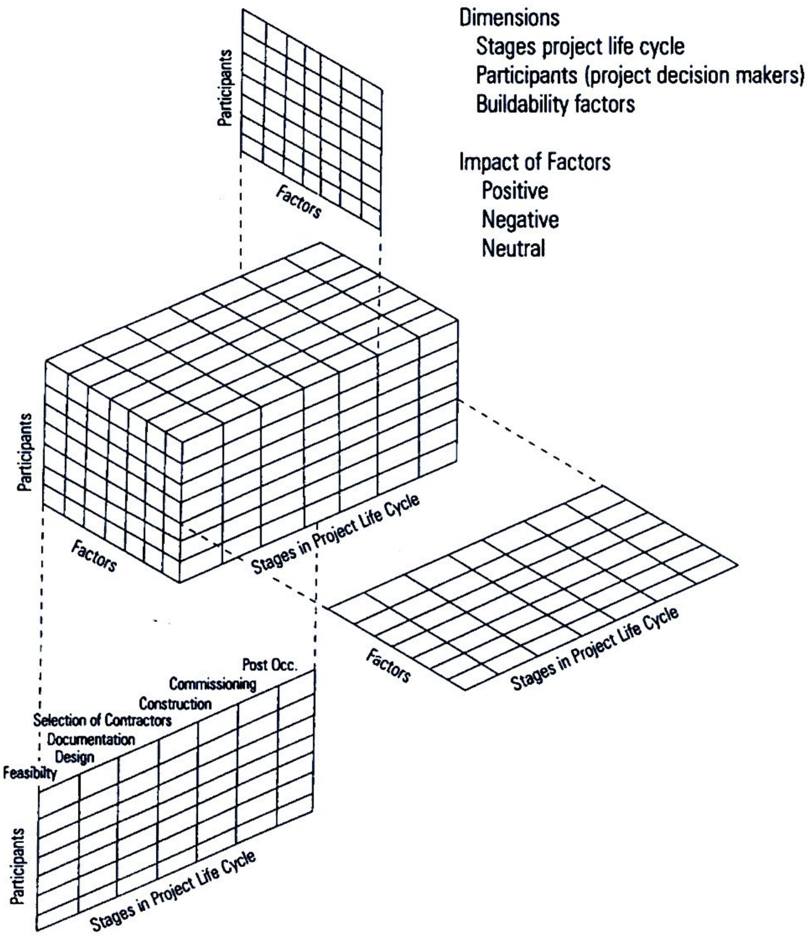

Figure 2 Three dimensional conceptual model of buildability [11].

Another important systems consideration of buildability that may inform the knowledge base of design for disassembly is the concept of trade packages. It is common practice to consider the construction process in terms of the type of work being done, each type usually being performed by a specialist sub-contractor. The boundaries of these packages are usually related to a particular type of building component or sub-assembly, such as electrical systems, plumbing, air conditioning, structure, cladding, glazing, concrete, etc. It is usual to schedule the construction process in terms of these trade packages such that they will occur in a particular sequence to allow for the optimum assembly procedure, good buildability. [12]

As already noted the disassembly process may be a direct reversal of the assembly process and it should ideally be so if total component reuse is desired. However if the goal of disassembly is the recycling of materials (rather than reuse of components) the process of disassembly may be other than a direct reversal of the assembly process, and the notion of trade packages will be obsolete. Trade packages concern themselves with particular component types, not necessarily with material types. If the goal of disassembly is recycled materials, the order in which things are disassembled need not relate to trade packages.

It can be seen then that there are a number of systems issues about how buildability is achieved that may be valuable in developing an understanding of how disassembly might be achieved, and in particular how it might be designed for.

Buildability Principles

The second major aspect of research into buildability is that of heuristic design principles. These are rules of thumb about the design of the building that an architect or building designer might employ in order to ensure the good buildability of a project. Several researchers have produced sets of such principles, usually from analysis of case studies of buildings that achieved good buildability in comparison with case studies of buildings with poor buildability.

Different researchers have developed their principles in different ways but there is much common ground in these proposed strategies. These strategies cover issues such as access, timing, skill levels, repetition, tolerances and sequences. CIRIA [13], in their study of the construction industry, identified seven general principles of buildability:

- Carry out thorough investigation and design
- Plan for essential site production requirements
- Plan for a practical sequence of building operations and early enclosure
- Plan for simplicity of assembly and logical trade sequences
- Detail for maximum repetition and standardisation
- Detail for achievable tolerances
- Specify robust and suitable materials

For each of these seven principles a number of recommendations are made, resulting in a total of twenty-four recommendations. Some of these recommendations will not have any relevance to the issues of disassembly. For example, ‘the design and shape of reinforced concrete elements should encourage the re-use of formwork’ [14]. While the re-use of formwork is good practice in construction, it will have no relevance in disassembly since the curing of wet concrete is one of the few assembly actions that is not reversed in the disassembly process. From the twenty-four recommendations, eleven are relevant to the issues of design for disassembly.

Adams [15], in his later discussion of CIRIA research, simplifies the analysis by proposing only three principal criteria for good buildability:

- Simplicity
- Standardisation
- Clear communication

These three criteria are then developed into sixteen design principles for good buildability [16]. Similar to the earlier CIRIA study, only some of these principles are relevant to issue of design for disassembly. Nine of the sixteen can be seen to have general relevance to disassembly, the remainder being either too specific in the form of prescriptive guidelines, or being related to assembly procedures that have no equivalent in a disassembly sequence.

Several other research efforts have also produced strategies or criteria for good buildability, though not in as much detail as the CIRIA work. In a report prepared for The Construction Industry Institute (CII) Constructability Task Force, by O'Connor, Rusch and Schultz [17], seven key buildability concepts or strategies are identified:

- Construction-driven planning and programming
- Design simplification
- Standardisation and repetition of design elements
- Specification development for construction efficiency
- Modular and pre-assembly designs should be developed to facilitate prefabrication and installation
- Designs should allow for accessibility of labour, materials and plant
- Designs should facilitate construction under adverse weather conditions

Research in Australia includes that of the Construction Industry Institute, Australia (CII, Australia). This research has resulted in several publications [18] which have presented explicit constructability, or buildability, principles. Within these publications are twelve principles from the CII, Australia, which represent broad criteria for consideration of buildability issues. As such they provide a framework for considering the problems. The principles are:

- Integration
- Construction knowledge
- Team skills
- Corporate objectives
- Available resources
- External factors
- Program
- Construction methodology
- Accessibility
- Specifications
- Construction innovation
- Feedback

DESIGN FOR DISASSEMBLY PRINCIPLES

These strategies, or principles, and others from related buildability research [19][20] have been studied for possible application in designing for disassembly. Those principles that may have relevance to the process of design for disassembly are shown in Table 1. While not all principles of buildability will be relevant to design for disassembly, it is also true that not all principles of design for disassembly will come from buildability. This table shows only those principles that have been informed by buildability sources.

Table 1 Design for Disassembly principles from Buildability Research

No.	Principle	Reference
1	Minimise the number of different types of components - this will simplify the process of sorting on site and make the potential for reprocess more attractive due to the larger quantities of same or similar items	Adams 1989, Chen 1994, Hon 1988
2	Use an open building system where parts of the building are more freely interchangeable and less unique to one application - this will allow alterations in the building layout through relocation of component without significant modification	CIRIA 1983, Hon 1988
3	Use modular design - use components and pre-assembled subassemblies that are compatible with other systems both dimensionally and functionally	Adams 1989, Chen 1994, CIRIA 1983, Hon 1988, Illingworth 1993
4	Use assembly technologies that are compatible with standard building practice - specialist technologies will make disassembly difficult to perform and may require specialist labour and equipment that makes the option of reuse more difficult	Adams 1989, CIRIA 1983, Miller 1990
5	Provide access to all parts of the building and all components – ease of access will allow ease of disassembly, if possible allow for components to be recovered from within the building without the use of specialist plant equipment	Adams 1989, Hon 1988
6	Use components that are sized to suit the intended means of handling – allow for various possible handling options at all stages of assembly, disassembly, transport, reprocessing, and re-assembly	Adams 1989
7	Provide a means of handling components during disassembly – handling during disassembly may require points of connection for lifting equipment or temporary supporting devices	Adams 1989, Illingworth 1993
8	Provide realistic tolerances to allow for movement during disassembly – the disassembly process may require greater tolerances than the manufacture process or the initial assembly process	Adams 1989, CIRIA 1983, Hon 1988, Illingworth 1993, Miller 1990
9	Design joints and connectors to withstand repeated use - to minimise damage and deformation of components and materials during repeated assembly and disassembly procedures	CIRIA 1983
10	Allow for parallel disassembly rather than sequential disassembly - so that components or materials can be removed without disrupting other components or materials, where this is not possible make the most reusable or 'valuable' parts of the building most accessible, to allow for maximum recovery of those components and materials that are most likely to be reused	CIRIA 1983, Miller 1990
11	Use prefabricated subassemblies and a system of mass production - to reduce site work and allow greater control over component quality and conformity	CIRIA 1983, Hon 1988
12	Provide spare parts and on-site storage for them - particularly for custom designed parts, both to replace broken or damaged components and to facilitate minor alterations to the building design	CIRIA 1983
13	Sustain all information on the building manufacture and assembly process – measures should be taken to ensure the preservation of information such as 'as built drawing', information about disassembly process, material and component life expectancy, and maintenance requirements	Adams 1989, CIRIA 1983

CONCLUSIONS

Research into buildability is still relatively new and not especially well developed, but there have already been major developments in identifying strategies, systems, and principles that will help to achieve better assembly. Such strategies and principles can be adopted by, and adapted for, design for disassembly by simple extending responsibility for the building beyond its service life and using the same design techniques that promote good assembly to promote good disassembly. In essence design for disassembly is just a logical, and environmentally preferable, extension of design for assembly. The knowledge base already partially exists.

Design for disassembly needs to concern itself with a holistic view of the project goals. These might be the reduction of waste through materials recycling, or through component reuse, or even total building relocation. A thorough understanding is however needed of these goals in order to understand the dimensions of the problem: the participants, the disassembly factors, and the project life cycle. Only with an understanding of these dimensions can heuristic design principles be appropriately employed, to achieve the project goals.

Design for disassembly may in the short term have added economic and possibly environmental costs, but on the much larger scale of the life cycle of resources, the long term benefits are potentially much greater. Design for disassembly may not always be appropriate, as design for ease of assembly may not be. But in the construction industry, which is responsible for such a large portion of our resource use and waste production, it is a strategy worthy of exploration.

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